7.6 THE ROLE OF COMBINATION TECHNIQUES IN MAXIMIZING THE UTILITY OF PRECIPITATION ESTIMATES FROM SEVERAL MULTI-PURPOSE REMOTE-SENSING SYSTEMS

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1. INTRODUCTION

Multi-purpose remote-sensing products from various satellites have proved crucial in developing global estimates of precipitation. Examples of these products include low-earth–orbit and geosynchronous-orbit infrared (leo- and geo-IR), Outgoing Longwave Radiation (OLR), Television Infrared Operational Satellite (TIROS) Operational Vertical Sounder (TOVS) data, and passive microwave data such as that from the Special Sensor Microwave/ Imager (SSM/I). Each of these datasets has served as the basis for at least one useful quasi-global precipitation estimation algorithm; however, the quality of estimates varies tremendously among the algorithms for the different climatic regions around the globe.

2. GENERAL ISSUES

It is "obvious" that the various precipitation datasets can be combined in some fashion that draws on the strengths of each dataset to provide a "best" estimate of the global precipitation patterns, but the barriers to practical implementation are substantial. The preeminent difficulty is the lack of quality validation data over the range of climatic conditions for which we wish to make estimates. Dense arrays of rain gauges are considered the most reliable validation, and such sites mostly occur in developed countries at mid-latitudes over land. It is difficult to correctly extend these regionally-biased, scattered validation results to the vast expanse of the globe for which validation data are poor (many land areas) or totally lacking (most oceanic regions). As a result, researchers are left to base the improvement and choice of algorithms on relative comparisons among the various candidate datasets. Within these limitations, the SSM/I-based algorithms are preferred over the other algorithms because the remotely sensed signal (upwelling radiant energy in various microwave frequencies) is more closely related to the occurrence of hydrometeors than in the other sensors.

A second substantial problem is that low-earth–orbit satellites only sparsely sample a given location. A single SSM/I averages 1.2 overpasses per day at the equator, while the National Oceanic and Atmospheric Administration (NOAA) series averages almost 2 overpasses per day. These return periods are long compared to the correlation times of precipitation events, so time-average estimates based on a single satellite contain substantial uncertainty. Furthermore, the return periods are long compared to the timescale of the diurnal cycle, so a single satellite has the strong likelihood of providing biased estimates of the daily total precipitation, particularly when the orbit is sun-synchronous. As a result, data from geosynchronous-orbit satellites are preferred because their observation interval is typically 1-3 hr.

In common with many, but not all, researchers who compute combination precipitation estimates, the authors adopt the philosophy that the apparently least biased and most accurate precipitation estimates should be used to calibrate other, less-trusted estimates before combinations are computed. We emphasize performing the calibration using data subsets that are as nearly coincident in space and time as possible. For example, our Adjusted Geosynchronous Operational Environmental Satellite (GOES) Precipitation Index (AGPI) uses approximately time/space-matched SSM/I and geo-IR precipitation estimates over a month to derive spatially varying corrections which are then applied to the full GPI data set. Once the AGPI is computed we decline to combine its monthly average with the monthly average of the calibrating SSM/I estimates because the SSM/I estimates are likely diurnally biased and noisier.

The combination techniques are designed to produce better answers globally than the individual input datasets, but it is clear from the outset that users interested in a specific regions must consider the datasets' performance for their own needs.

3. MONTHLY ESTIMATES

Combinations at the monthly 2.5°x2.5° latitude/longitude resolution have almost a decade of heritage because at those scales the sampling errors are contained for low-orbit satellites and relatively good for geosynchronous-orbit satellites. Most recently, the Global Precipitation Climatology Project (GPCP) Version 2 combination product was developed and released by the authors (an extension of Huffman et al. 1997), providing a globally complete estimate of monthly precipitation on a 2.5°x 2.5° grid for the 21-year period 1979 – (delayed) present.

The combination of satellite data into a multi-satellite (MS) product is carried out differently during 3 periods according to data availability. Strong efforts were made to homogenize the data record:

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- *1979 to 1985* (OLR Precipitation Index – OPI) The OPI was calibrated against the 1988-1998 GPCP satellite-gauge (SG) product for calibration. That is, at each gridbox month-to-month OLR anomalies from climatology are regressed against SG anomalies, and a fallback direct regression of OLR against SG is computed.
- *1986 to Mid-1987* (geo-IR, OPI) The MS is composed of geo-IR GPI scaled by SG-scaled OPI in 40°N-S and the SG-scaled OPI elsewhere.
- *Mid-1987 to the Present* (geo-IR, TOVS, SSM/I) TOVS is merged in with SSM/I where the SSM/I is suspect (outside about 45°N-S) or missing. In the band 40°N-S the bias of the geo-IR GPI is adjusted to that of the SSM/I, producing the AGPI. The MS is composed of AGPI in the band 40°N-S and the merged TOVS–SSM/I elsewhere.

In each of the periods the MS and a gauge analysis are linearly combined into the SG combination using weighting by inverse estimated mean-square error for each individual estimate.

A similar dataset is being computed for the Tropical Rainfall Measuring Mission (TRMM) in the band 40°N-S using the TRMM Microwave Imager (TMI)-Precipitation Radar (PR) multisensor precipitation estimate to calibrate the GPI. It covers the TRMM period [1998 – (delayed) present].

4. DAILY ESTIMATES

GPCP began collecting a finer scale global geo-IR dataset in late 1996, enabling development of a correspondingly finer scale set of precipitation estimates. The GPCP One-Degree Daily (1DD) dataset is the authors' first technique for estimating global daily precipitation at the 1°x1° scale from observationally based data. It is currently available for 1997 – (delayed) present (Huffman et al. 2001).

Where possible, (40°N-S) the Threshold-Matched Precipitation Index (TMPI) provides GPI-like precipitation estimates in which:

- the geo-IR T_b threshold (T_{b0}) is set locally from month-long accumulations of time/space coincident geo-IR T_b and SSM/I-based precipitation frequency; and
- the conditional rain rate is set locally from the resulting frequency of $T_b<T_{b0}$ for the <u>entire</u> month and the GPCP SG.

Scaled low-orbit IR GPI is used to fill holes in individual 3-hrly geo-IR images.

Outside 40°N-S the 1DD is based on TOVS:

- the number of TOVS rain days are reduced to match TMPI rain days;
- TOVS precipitation by zeroing the (1–ratio) smallest daily TOVS rain accumulations; and
- the remaining (non-zero) TOVS rain days are rescaled to sum to the monthly SG.

The time series of the global images shows good continuity in time and space across the data boundaries. Validation against dense raingauges for individual grid boxes values shows a very high RMS error, as expected, but statistics improve when time/space averaging is performed.

5. THREE-HOURLY ESTIMATES

Currently we are working towards global 3-hourly precipitation fields. At present we are experimenting with the geo-IR zone (40°N-S). Similar to the 1DD, we

- scale SSM/I estimates to TRMM TMI estimates;
- combine the TMI and scaled SSM/I to create a high-quality (HQ) estimate;
- make geo-IR pixel rainrates a function of the depression of the T_b below the HQ-based T_{b0} threshold; and
- replace geo-IR estimates with the HQ estimates, where available.

There are substantial questions about how to perform the combination, but working at the instantaneous level avoids the diurnally sampling bias issue.

6. FUTURE PROSPECTS

The continued acceleration of computing power has now enabled the production of essentially full-resolution, half-hourly (when available) global geo-IR datasets. At the same time, the National Aeronautics and Space Administration has proposed development of the Global Precipitation Mission (GPM). GPM is planned to provide global 3-hourly passive microwave data by adding new, low-cost satellites to fill the gaps in current and planned passive microwave satellites, and to provide a TRMM-like satellite to calibrate all the passive microwave estimates on an on-going basis. We expect a permanent role for the geo-IR in filling the inevitable gaps in microwave coverage, as well as enabling sub-3-hourly precipitation estimates at fine spatial scales. As well, we expect a great deal of development of theory and application for estimating errors in the various estimates. Realizing the potential of these datasets will require a long-term research effort and continued cultivation of long-term, high-quality raingauge networks for validation and direct combination with the satellite-based estimates.

7. REFERENCES

Huffman, G.J., R.F. Adler, S. Curtis, M. Morrissey, J.E. Janowiak, B McGavock, J. Susskind, 2001: Global Precipitation at One-Degree Daily Resolution from Multi-Satellite Observations. *J. Hydrometeor.*, in revision.

Huffman, G.J., R.F. Adler, P. Arkin, A. Chang, R. Ferraro, A. Gruber, J. Janowiak, A. McNab, B. Rudolf, U. Schneider, 1997: The Global Precipitation Climatology Project (GPCP) Combined Precipitation Data Set. *Bull. Amer. Meteor. Soc.*, **78**, 5-20.